

United State Patent Application

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Title of the Invention:

UNIFORM ELECTROPLATING OF WAFERS

Related U.S. Application Data:

References Cited

U.S. Patent Documents

T-0020

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Summary of the Invention

The non-uniformity of electroplating on wafers is due to the appreciable resistance of the thin seed layer and edge effects. Mathematical analysis of the current distribution during wafer electroplating reveals that the ratio between the resistance of the thin deposited seed layer and the resistance of the electrolyte and the electrochemical reaction determines the uniformity of the electroplated layer. Uniform plating is critical in wafer

metallization for the subsequent step of chemical mechanical polishing of the wafer. Based on the analysis, methods to improve the uniformity of metal electroplating over the entire wafer include increasing the resistance of the electrolyte, increasing the distance between the wafer and the anode, increasing the thickness of the seed layer, increasing the ionic resistance of a porous separator placed between the wafer and the anode, establishing contacts at the center of the wafer, and jet electroplating by placement of a rotating distributor in front of the wafer. The rotating distributor generates multiple jets hitting the surface of the wafer, thus ensuring conformal electroplating. The jets can be either submerged in the electrolyte or above the level of the electrolyte. The distribution of holes in the distributor determines the distribution of electroplated metal on the wafer. The shape and uniformity of the electroplated layer can also be determined by the shape and relative size of the counter-electrode (anode), by masking the edge of the wafer and by periodically reversing the plating current. The problem of uniformity is more severe as the diameter of the wafer becomes larger.

~~18 claims, 5 drawing sheets~~

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a plating device for achieving uniform plating of a wafer.

2. Background:

Copper Interconnect Technology

One of the primary challenges in IC design and fabrication is overcoming signal propagation delays, which are caused by resistance and capacitance within devices and interconnects. In high-speed circuits, the RC time delay becomes important in the form of a need for high conductivity. The high speed, combined with smaller dimensions, has made interconnect technology the focal point of current research and development. There is no question that the need for low RC will require the use of new materials of lower resistance, such as copper, and low dielectric, such as polymers.

Aluminum is the most commonly used metal for metallization, along with its alloys and various silicides. However, in order to increase the conductivity, copper is expected to replace aluminum in the sub-0.25 μm technology, which is expected to be introduced into manufacturing within the very near future. Multilevel interconnect (MLI) technology will be used and consequently the interconnect current densities will be doubled, while contacts and cross-sectional areas will be decreased. This will result in higher power dissipation, calling for the introduction of highly reliable copper interconnect technology.

Copper appears to offer low RC performance and high reliability over the commonly used aluminum alloys. The current approaches to copper metallization include CVD (blanket and selective), selective electroless deposition, sputtering (PVD) and electrodeposition. The common approaches to copper patterning include CMP, RIE and selective deposition. Copper CVD is based on two precursor chemistries, commonly used for Cu(I) and Cu(II) (see Witty et al., 1993). The growth rate is about 50nm/min and the resistivity is 2 $\text{m}\Omega\text{-cm}$. Selective CVD of copper is preferred because fewer steps are needed, it is less expensive and smaller contacts and via can be filled. Many new and highly volatile Cu precursors have been developed, ranging from volatile solid Cu(I) coordination compounds to volatile liquid Cu(I) organometallics, which are capable of fast deposition of high purity Cu films at moderate temperatures. However, the various CVD processes for copper are expensive and relatively slow. It appears that electrochemical deposition of copper is the leading technology, as it offers low cost and fast deposition process. The main problems facing the commercialization of copper interconnect electrodeposition are the non-uniformity of the Cu layer over the wafer and the filling of small, high aspect ratio contact holes without void formation.

Because copper reacts with SiO_2 , it is necessary to form a barrier layer first. Tantalum (Ta) or tantalum nitride (Ta₃N₅) are pre-deposited on the SiO_2 by sputtering. Cu seed layer is needed next for good electrical contact and adhesion, thus thin Cu seed layer (500-1000Å) is formed by sputtering or by CVD. In order to avoid any contact between the devices and copper, the first contact holes are filled with tungsten (W) sputtering. Copper electroplating is obtained from an aqueous solution of CuSO_4 and H_2SO_4 , in the presence

of several additives and leveling agents. The electroplating is performed while the wafer is rotating at a speed of up to 2,000 rpm, while the electrolyte is pumped against the wafer in the form of a stagnation flow. Electrical contacts are established by hooks or a contact ring attached to the periphery of the wafer. This creates non-uniform current distribution due to the non-uniformity of the rotating disk geometry and due to the low resistivity of the thin copper layer (terminal effect). Using 8" wafer, the non-uniformity of the layer thickness reaches 9-15% 1σ , as the thickness at the edge is 13-15KA, while in the center the thickness is 7.5-10 KA. This results in losing as much as 1.5" of edge during polishing, as the edge remains Cu-covered while the center area is completely polished. Commercial electroplating units include Equinox and LT-210 made by Semitool, Montana (U.S. patents 5,230,743 and 5,445,172), in which the wafer is held by flexibly mounted gripping fingers. Another source is EEJA (Electroplating Engineers of Japan), where the contact hooks are replaced by a contact ring and air bag (U.S. patent 5,429,733). All these electroplating systems suffer from non-uniform distribution of plating, resulting in excess of electroplated metal at the circumference edge of the wafer. Literature on copper technology is available at VMIC conference proceedings (Rathore & Nguyen 1997, Ting 1997, VMIC 1997).

Copper interconnect technology requires the use of damascene processing because etching of copper is extremely difficult. Damascene processing involves the formation of interconnect lines by first etching trenches in a planar dielectric layer, and then filling these trenches with the metal, such as aluminum or copper (Singer 1997). After filling, the metal and the dielectric are planarized by chemical-mechanical polishing (CPA). In dual damascene processing, a second level is involved where series of holes (contacts or via) are etched and filled in addition to the trenches. Dual damascene will mostly be the patterning choice for copper interconnects (Singer 1997).

Current Distribution of Metal Electroplating on Wafers

The current distribution for metal electroplating on wafers has been analyzed (see Jorne 1997). The non-uniformity of the plating is due to the appreciable resistance of the thin

seed layer and the geometry of the electroplating system. When the current is fed from the circumference edge of the wafer, a non-uniform plating occurs as thicker metal deposit occurs at the edges. The ratio between the resistance of the thin metal layer and the resistance of the electrolyte and the electrochemical reaction determines the uniformity of the electroplating. Increasing the diameter of the wafer and the resistivity of the seed layer results in non-uniformity, while increasing the resistivity of the electrolyte and the electrochemical reaction results in higher uniformity.

A mathematical analysis of the plating current distribution over the wafer (Jorne 1997) shows that the electroplating current density is given by

$$i_z/i_{avg} = (B/2)I_0(Bx)/I_1(B)$$

where i_z and i_{avg} are the local and average current densities, respectively. I_0 and I_1 are the modified Bessel functions of order 0 and 1, respectively. $x=r/R$ is the ratio of the local radius r to the outer radius of the wafer R , and B is the plating uniformity parameter defined by

$$B^2 = (\rho/\rho_{el})(R^2/Wd)$$

where ρ and ρ_{el} are the resistivities of the electroplated metal and the electrolyte, respectively, R is the radius of the wafer, W is the thickness of the seed layer and d is the distance between the wafer and the counter electrode. In order to ensure uniformity during electroplating, the electroplating system must obey that the value of B is smaller than unity: $B^2 \leq 1$. The current distribution, and hence the thickness distribution of the electroplated metal depends on a single parameter B , which represents the ratio between the resistance of the deposit and the electrochemical resistance of the electrolyte and the electrochemical reaction. For small B ($B^2 \leq 1$), the plating distribution is fairly uniform, however, for large B ($B^2 \geq 1$), the plating distribution becomes progressively non-uniform as the deposit at the circumference becomes thicker.

SUMMARY OF THE INVENTION

The present invention describes several electroplating devices for the uniform metallization of wafers for interconnect technology. The invention addresses in particular the problem of achieving uniform plating distribution over the entire wafer and the conformity to sub-micron features. The wafer, on which a thin barrier layer and seed layer are pre-deposited, is brought in contact with an electrolytic solution made of a salt of the metal to be deposited, supporting electrolytes and leveling agents. Because the seed layer is very thin, the electroplating rate becomes lower at further distances from the contact point, as the electrical current has to flow through the high-resistance thin seed layer. In conventional wafer plating systems, the wafer is held at its edge by gripping fingers or a contact ring, through which the electrical current is fed. This usually results in higher plating at the circumference edge, creating severe problems during the subsequent chemical-mechanical polishing step. In the present invention, the current distribution during wafer electroplating is mathematically analyzed. The uniformity of electroplating depends on the ratio of the resistance of the seed layer to the resistance of the electrolyte and the electrochemical reaction. Uniformity of electroplating can be achieved by maintaining the uniformity parameter B below a certain value, usually below unity. This can be achieved by decreasing the seed layer resistance, increasing the electrolyte resistance, increasing the distance between the wafer and the counter electrode, by a jet electroplating using a rotating distributor, and by increasing the electrical resistance of a porous separator which is placed between the wafer and the counter electrode. Jet electroplating can be achieved by pumping the electrolyte through a rotating distributor with small holes (rotating shower head). The resulting multiple jets hit the surface of the wafer thus ensuring uniform and conformal electroplating, in the presence or in the absence of leveling agents and brightening additives. Predetermined distribution of electroplating can be achieved by nonuniform distribution of holes in the distributor. The more holes per unit area results in heavier electrodeposit on the corresponding area of the wafer facing the distributor. Furthermore, the uniformity of the electroplated layer can be determined by the shape and size of the counter electrode and its position relative to the wafer. Uniformity can be achieved also by periodically reversing the current during plating, thus preferentially dissolving the excess metal from

areas where the electroplating was higher. In addition, instead of the wafer being electrically connected by contact grips at the edge, the wafer could rest on vertical contact pegs placed in the electrolyte and electrically isolated from the electrolyte. Only the tips of these pegs touch the active side of the wafer to be plated. The wafer, resting on contact pegs or a contact ring, is rotating, while the electrolyte solution is being upwardly pumped against the wafer in order to achieve uniform concentration in the electrolyte, good conformity and uniform plating distribution. The electrical contact points can be also distributed over the entire surface of the wafer, preferentially at the center, thus eliminating thicker electroplating at the edges and ensuring uniformity over the entire wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of an electroplating apparatus, showing the contact fingers or ring and the wafer being rotating while the electrolytic solution is circulated against the wafer. The edge of the wafer is shielded from being heavily plated by an insulating ring.

Fig. 2 shows an electroplating apparatus, in which the wafer is resting on several contact pegs vertically located in the electrolyte. The electrical current is distributed over the entire wafer, thus eliminating plating non-uniformity.

Fig. 3 is a schematic view of submerged jet electroplating apparatus showing a stationary wafer, while the electrolyte is circulated against the wafer through a circular distributor, in which many holes are drilled in an angle in such a way that the circulating electrolyte causes the distributor to rotate. The electrolyte is emerging from the holes as submerged jets, thus improving the conformity and uniformity of the deposit.

Fig. 4 is a schematic view of jet electroplating apparatus in which the electrolyte level is maintained below the wafer, and where the electrolyte is pumped through a rotating distributor and forms multiple jets hitting the wafer. The wafer is not submerged in the electrolyte and only the multiple jets serve as electrolyte paths for the current.

Figure 5 shows a schematics of the rotating distributor. The electrolyte is pumped through the holes of the distributor and emerges as multiple jet hitting the wafer. Some of the holes are drilled in an angle, causing the distributor to rotate.

DESCRIPTION OF PREFERRED EMBODIMENT

The preferred embodiments will be discussed hereinafter with reference to the drawings. The wafer 1 is obtained by lithographic etching and deposition processes, commonly used in the microelectronics industry. The sub-micron width or diameter of the trenches and via holes are, as a typical example, about 0.25 micron, with a high aspect ratio, typically as an example, of about 1:4. Thus the depth of the trenches or holes could be about 1 micron or more. The barrier layer typically consists of Ta or TaN or other metals or compounds capable of preventing the diffusion and reaction of the intended interconnect metal, say copper for example, with the dielectric, say SiO₂ for example. The barrier layer is usually obtained by CVD, PVD or sputtering. Seed layer of the metal 10, say copper for example, is deposited on the barrier layer in order to act as the conducting electrode for the subsequent electroplating of the metal. The seed layer is obtained by CVD, PVD or sputtering to a typical thickness of about 0.1 micron. The seed layer is fully conformed to the walls of the patterned trenches and holes and via.

The wafer 1 is then transferred to the electroplating apparatus 7 as it is facing down gripped by the contacts 9, as shown in Fig. 1. The contacts 9, as shown in Fig. 1, consist of metallic conductor 3, electrically insulated from the electrolytic solution by a plastic insulator 14, except at the tips which are in direct contact with the electroplated metal 10 on the wafer 1. The rotation is designed to ensure uniformity of the plating and averaging possible disturbances. The electrolyte 6 is pumped upwardly against the surface of the wafer to ensure sufficient supply of reacting ions to the surface and into the sub-micron trenches and holes and exits by flowing over the overflow 16 which determines the level of the electrolyte in the apparatus 7. The electrolyte is circulated from outer reservoir 25 by pump 26 into the inner reservoir 27. A porous separator 8 is located between the anode 2 and the wafer 1 to ensure even distribution of the flow 6 over the entire wafer 1. The porosity and thickness of the porous separator 8 also determines the electrical resistance of the electrolyte and the uniformity of the electroplating 10 on the wafer 1. A masking ring 12 is placed at a certain distance from the wafer to shield the edge of the wafer from heavy electroplating there. The anode 2, made of the plated metal, is located below the wafer and is usually smaller in diameter than the wafer itself. The circumference edge of the wafer is masked by a plastic ring 5 which masks the edge by

forming a less than 90 degree angle of contact, as shown in Fig. 1. The wafer is resting on the ring 5 and the contacts in such a way that its backside is not submerged in the electrolyte and only the active side of the wafer is in contact with the fountain of electrolyte 6 formed by pumping the electrolyte against the wafer 1.

Fig. 2 shows a design of an electroplating device where the electrical current is distributed through several contact points 9, thus eliminating the non-uniformity in electroplating. The wafer 1 is resting, facing downward, against several pegs 14 vertically positioned inside the electrolyte. The tips 9 of these pegs 14 are in electrical contact with the active face of the wafer where electroplating is taking place 10. The electrical wires 15 are insulated from the electrolyte by the insulating pegs. The wafer 1 is resting also on an insulating ring 5, which masks the edge of the wafer 1 from developing thick deposit. The entire contact pegs assembly 14 and the insulating ring 5 and the wafer 1 are rotating while electrolyte 6 is pumped upwardly against the surface of the wafer to ensure uniformity and conformity to the high aspect ratio trenches and holes, previously etched in the wafer. A masking ring is placed at a certain distance from the wafer to shield the edge of the wafer from heavy electroplating there. A porous separator 8 is located between the anode 2 and the wafer 1 to ensure even distribution of the flow 6 over the entire wafer 1. The porosity and thickness of the porous separator 8 also determines the electrical resistance of the electrolyte and the uniformity of the electroplating 10 on the wafer 1. The electrolyte is circulated by a pump 26 from the outer reservoir 25, through the feeding pipe 28 into the inner reservoir 27.

Fig. 3 shows a design of electroplating apparatus where the wafer is stationary and a rotating distributor 21 is placed in close proximity to the wafer. The distributor 21 is made of a plastic disk with many holes 22, some are drilled in an angle to the direction of the flow of the electrolyte. The electrolyte is pumped through these holes, causing the distributor to rotate, sending multiple jets of electrolyte 23 impinging on the stationary or rotating wafer 1. The distribution of holes on the rotating distributor determines the local distribution of electroplating on the wafer. The more holes per unit area results in thicker electroplating there. It is possible to set the distribution of electroplating by the density of holes in various radial positions on the distributor. The rotating distributor is resting on a pin 24, centrally located on top of the feed pipe 28. The electrolyte is pumped from the

outer reservoir 25 by a pump 26 and into the inner reservoir 27, through an inlet 28 located below the anode 2. The electrolyte passes around the anode 2 and through the porous separator 8, and then upward through the rotating distributor 21 and emerges in the form of multiple jets 23 impinging on the wafer 1. The electrolyte 6 then overflows over the smooth edge 16 of the inner reservoir 27 to the outer reservoir 25. A plastic ring 5 shields the edge of the wafer from heavy electroplating there. The electrical contacts 9 are made from the metal being deposited (e.g. copper) and are not insulated, thus serving as current thieves, preventing heavy deposit at the contact points. The inner reservoir 11 is placed inside the outer reservoir 7 and resting on several legs 29. A porous separator 8 is placed between the anode 2 and the rotating distributor 21 in order to increase the electrical resistivity of the electrolyte 6. The wafer 1 is resting on several electrical contacts 9 and the current is fed by wires 3. The wafer 1 is pressed against the contacts 9 by the cover of the reservoir 30.

Fig. 4 shows a design of an electroplating apparatus in which the wafer is stationary and the level of the electrolyte is maintained below the face of the wafer. The electrolyte is pumped by a pump 26, through the inlet 28 into the inner reservoir 27, where it flows around the anode 2 and up against the rotating distributor 21. The distributor is made of a plastic disk through which many holes 22 are drilled, some in an angle to the direction of the flow. This allows the distributor 21 to rotate, while the electrolyte emerges in the form of multiple jets, hitting the face of the stationary or rotating wafer 1. The distributor rests on a pin 24, centrally located on top of the inlet pipe 28. The electrolyte overflows over the smooth edge 16 of the wall 11 of the inner reservoir 27 into the outer reservoir 25. The inner reservoir 11 is placed inside the outer reservoir 7 and stands on several legs 29. The distance between the rotating distributor and the wafer is small to allow an effective impinging flow which is necessary to achieve conformity and uniformity during the electroplating of the wafer. The overflow maintains that the level of the electrolyte in the inner reservoir 27 is slightly above the rotating distributor 21.

Fig. 5 shows the rotating distributor 21. It consists of plastic disk through which multiple holes 22 are drilled. Some of the holes are drilled in an angle to the flow direction, thus causing the distributor 21 to rotate around its axis 24. The electrolyte emerges from the holes as multiple jets, hitting the surface of the wafer, where electroplating takes place.